Track based Triggers for long-lived particles decaying in ATLAS

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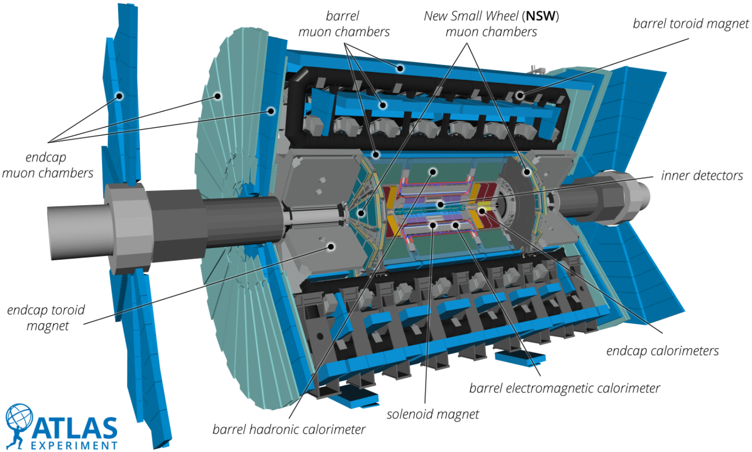
Particle Physics

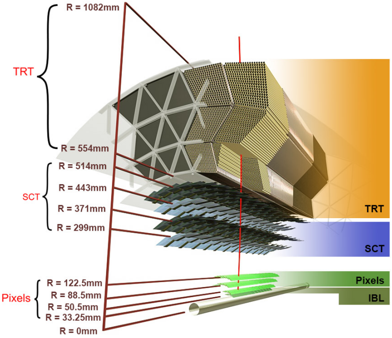
ATLAS



barrel
muon chambers
New Small Wheel (NSW)
muon chambers
barrel toroid magnet
endcap
muon chambers
inner detectors
endcap toroid
magnet
endcap calorimeters
barrel electromagnetic calorimeter
solenoid magnet
barrel hadronic calorimeter
ATLAS
EXPERIMENT

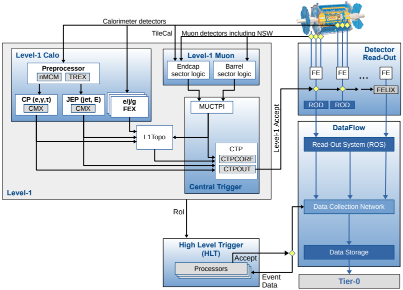
ATLAS (current) Inner Detector

- The ATLAS Inner Detector consists of 3 different subdetectors: Pixel, Silicon Microstrip (SCT) and Transition Radiation Tracker, surrounded by a 2T solenoid magnet
- All tracking in the trigger starts in the two silicon detectors, with an optional extension to the TRT
- The Inner Detector data is buffered on detector until a Level 1 Accept is received, tracking is therefore purely software based



Trigger System

- ATLAS uses a two level trigger system: a hardware based L1 system and a software based high level trigger.
- The hardware trigger consists of 3 major components: **L1Calo**, **L1Muon** and the **CTP**
- All detectors are readout upon receipt of a L1A from the CTP, including information about the L1 decision. The full detector data is then passed to the HLT for more complex decisions to be made

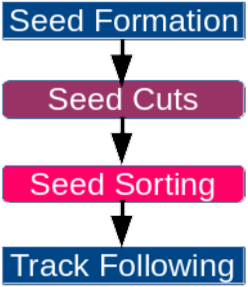


Trigger System

- The maximum Level 1 accept rate is 100 kHz, the output rate of the HLT is limited by the bandwidth of the storage system.
- A maximum of 8 GB/s can be written to storage. The HLT output rate in a normal run is therefore approximately 3kHz.
- Tracking is CPU intensive, so careful design of what tracking to run and when are needed to ensure resource limits are respected. Tracking makes up a significant proportion of all CPU used in the HLT farm

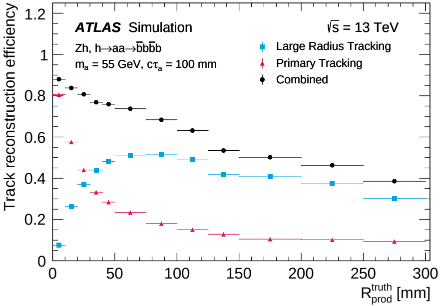
Track Reconstruction

- Track reconstruction is performed both in the HLT and offline processing
- It starts with seed formation when three silicon hits are combined together to form a triplet
- Cuts are imposed on triplets to reduce the number which must be processed to find tracks
- This triplet is then extended using a combinatorial Kalman filter through the rest of the silicon trackers.
- The standard track reconstruction is optimised for prompt particles, but has poor efficiency for tracks originating further out in the detector



Large Radius Tracking

- Large Radius Tracking (LRT) is an additional pass of tracking designed to reconstruct displaced tracks, by relaxing various cuts
- Until recently this version of LRT was expensive to run (even offline) and was therefore only used on preselected events
- The filter limits the sensitivity of analyses by limiting the statistics, as well as reducing the flexibility as changes require a full reprocessing.

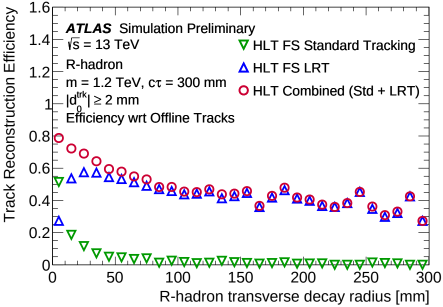


New LRT performance
IDTR-2021-03

LRT in the Trigger

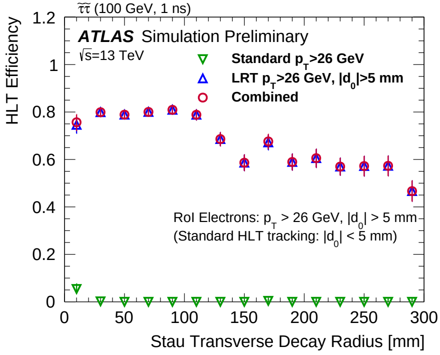
- Improvements in the performance of the trigger tracking software (FTF) enabled LRT to be added to the trigger for run 3. Additionally the design of LRT was modified to improve performance.
- Unlike standard tracking LRT only forms seeds using hits in the SCT, it also increases the maximum value of $|d_0|$ to 300 mm and $|z_0|$ to 500 mm. By requiring at least 8 silicon hits on a track, a track cannot begin after the first SCT layer.
- Additionally trigger LRT can be run using unused hits from the standard tracking

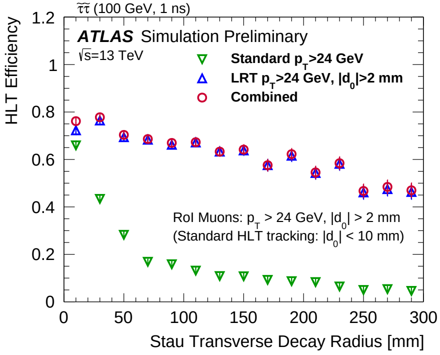
Expected performance of trigger LRT



The efficiency of fullscan large radius tracking measured using a 1.2 TeV R-hadron monte-carlo sample. The denominator of the efficiency is offline standard and LRT tracks which have been truth matched to particles from the R-hadron decay. Clusters used in the standard tracking are removed from consideration by LRT resulting in the low performance at low d_0

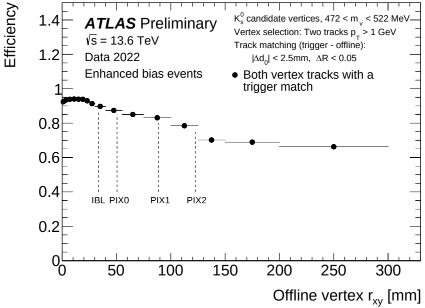
Expected performance of trigger LRT





Using a simulated sample of staus with a lifetime of 1ns and a mass of 100 GeV. The denominator of the efficiency is offline standard and LRT tracks which have been truth matched to electrons/muons from the stau decay.

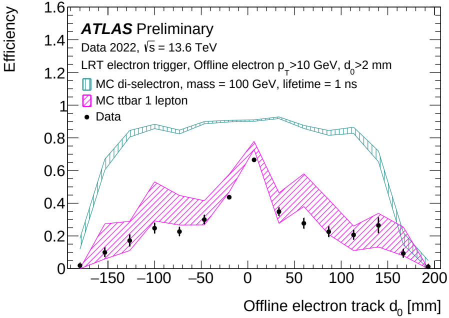
Performance of trigger LRT

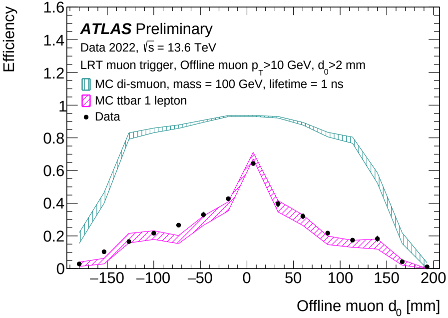


The performance of the fullscan LRT was measured by reprocessing a special run to add the fullscan LRT trigger, which is disabled ordinarily due to the high CPU cost associated with it.

The efficiency was calculated by reconstructing K_s vertices and counting LRT tracks matched with the offline tracks associated with the vertices.

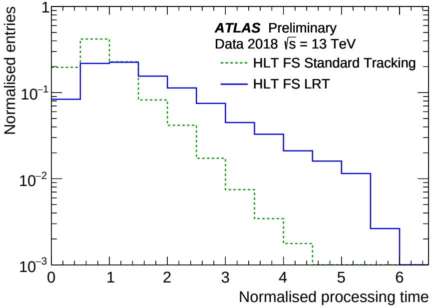
Performance of trigger LRT

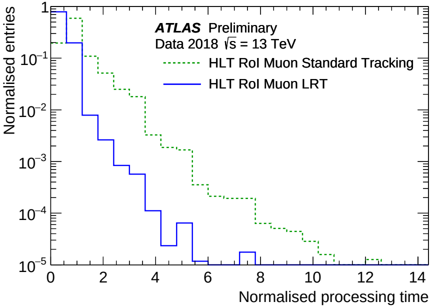




These plots show the efficiency after running both fast and precision trigger tracking vs offline tracking. The shaded bands show efficiency from monte-carlo samples. The black points show the efficiency measured in data.

Timing of trigger LRT

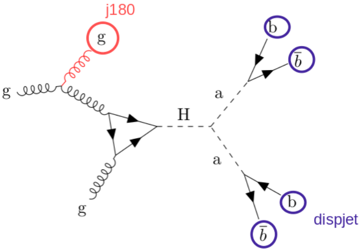


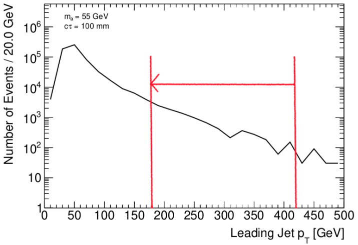


The number of seeds produced for fullscan LRT is higher which results in the increased processing time, whilst for muons the number of seeds is lower resulting in the reduced time.

Displaced Jet Trigger

- Triggering on a single low p_T jets is difficult as so many are produced in a collision, that trigger thresholds for a single jet must be high
- This presets challenges for some LLP production modes, which do not have additional objects e.g. leptons to trigger on
- Can use LRT to identify the displaced tracks, allowing for a low p_T threshold whilst retaining a low rate





Design of the Displaced Jet Trigger

- New trigger uses trigger LRT to reconstruct displaced tracks produced by the decay of long-lived particles. This tracking is run in RoIs chosen based on jets which are not associated with a significant number of prompt tracks.
- In order to identify jets with prompt tracks fullscan tracking (already run for other triggers) is used, this sets the minimum leading jet p_T threshold at 180 GeV, as fullscan tracking is expensive, and this is the lowest threshold current used within the trigger
- The trigger is divided into stages with the first responsible for identifying prompt tracks (using the fullscan tracks) and the second running LRT and identifying the displaced jets.

Design of Displaced Jet Trigger

Track Classification

	Prompt	Displaced
$\lvert d_0 \rvert$	< 3.0 mm	≥ 3.0 mm
$z_0 \sin(\theta)$	≤ 3.0	-
$\text{sig}(d_0)$	-	≥ 10

Jet Classification

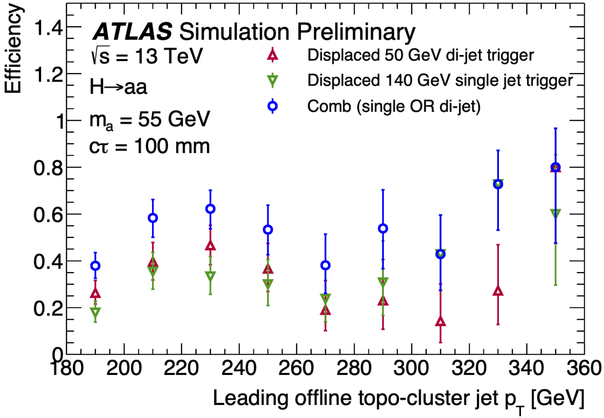
	2 jet		1 jet
Max Rank	3		-
p_T	≥ 50 GeV		≥ 140 GeV
	1p	3d2p	x3d1p
nDisp	≥ 0	≥ 3	≥ 3
nPrompt	≤ 1	≤ 2	≤ 1
Max unclassified track fraction	≤ 0.75		

Design of the Displaced Jet Trigger

In order to obtain the best performance three different trigger chains with differing requirements are defined:

1. Requires 2 jets passing the `3d2p` cut
2. Requires 1 jet to pass the `3d2p` cut and another which passes the `1p` cut
3. Requires exactly one jet with p_{T} of at least 140 GeV which passes the `x3d1p` cut

Expected performance



Performance for a signal sample of a pair of pseudo-scalars decaying to 4 b quarks, produced from the decay of a Higgs produced via the ggF channel.

Summary

- For Run 3 the ATLAS trigger has been significantly upgraded introducing a whole new tracking capability which has been exploited to introduce new triggers targetting long-lived particles
- New triggers which significantly increase sensitivity to displaced leptons and jets have been added and are taking data